(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 407 841 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
14.04.2004 Bulletin 2004/16

(51) Int Cl.[7]: B22D 7/00, B22D 27/02, B22D 18/02, B22D 17/00, C22C 1/00

(21) Application number: 03253377.0

(22) Date of filing: 29.05.2003

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LI LU MC NL PT RO SE SI SK TR
Designated Extension States:
AL LT LV MK

(30) Priority: 25.09.2002 KR 2002058163
16.10.2002 KR 2002063162
17.01.2003 KR 2003003250
04.03.2003 KR 2003013516

(71) Applicant: Chunpyo Hong
Seoul (KR)

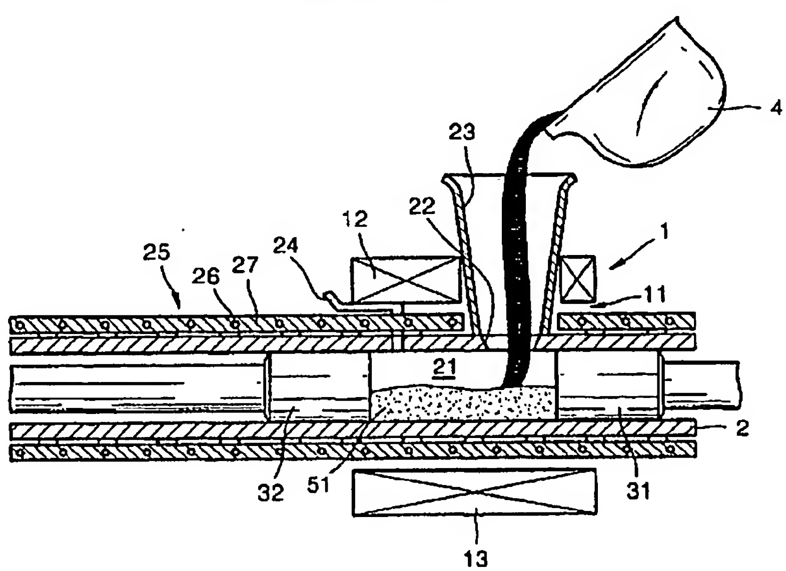
(72) Inventors:
- Chunpyo,Hong 108-502 Daerimhansuptown
Seoul (KR)
- Itamura, Masayuki
Ube-shi, Yamaguchi-ken (JP)

(74) Representative: Browne, Robin Forsythe, Dr.
Urquhart-Dykes & Lord
Tower North Central
Merrion Way
Leeds LS2 8PA (GB)

(54) Method and apparatus for manufacturing billets for thixocasting

(57) Provided are a method and apparatus for continuously manufacturing quality billets for thixocasting that have a fine, uniform, spherical particle structure, in a short time, with improvements in energy efficiency and mechanical properties, cost reduction, convenience of casting, and shorter manufacturing time. The method involves applying an electric field to a domain (21) of a sleeve (2) defined by first (31) and second (32) plungers inserted through each end of the sleeve and loading a molten metal into the domain of the sleeve to form a semi-solid metallic slurry (51), moving the first plunger toward the second plunger to compress the semi-solid metallic slurry and form a billet (52) via cooling, and shifting the billet toward the second plunger to discharge the billet from the sleeve.

FIG. 2



EP 1 407 841 A2

Printed by Jouve, 75001 PARIS (FR)

BNSDOCID: <EP_______1407841A2_I_>

Description

BACKGROUND OF THE INVENTION

[0001] This application claims priority from Korean Patent Application No. 2002-58163 filed on September 25, 2002, No. 2002-63162 filed on October 16, 2002, No. 2003-3250 filed on January 17, 2003, and No. 2003-13516 filed on March 4, 2003, in the Korean Intellectual Property Office, the disclosures of which are incorporated herein in their entirety by reference.

1. Field of the Invention

[0002] The present invention relates to a method and apparatus for manufacturing billets for thixocasting, and more particularly, to a method and apparatus for manufacturing billets, for thixocasting, with a fine, uniform, spherical particle structure.

2. Description of the Related Art

[0003] There are two close categories of semi-solid or semi-molten processes: rheocasting and thixocasting. Rheocasting refers to a process of manufacturing billets or final products from semi-solid metallic slurries having a predetermined viscosity through casting or forging. Thixocasting refers to a process involving reheating billets manufactured through rheocasting back into a metal slurry and casting or forging it to manufacture final products. Here, semi-solid metallic slurries consist of spherical solid particles suspended in a liquid phase in an appropriate ratio at temperature ranges for semi-solid state, and thus, they change form easily by a small force due to their thixotropic properties and can be cast easily like a liquid due to their high fluidity.

[0004] Such rheocasting and thixocasting are more advantageous than general casting processes using molten metal. For example, semi-solid or semi-molten slurries used in rheocasting or thixocasting have fluidity at a lower temperature than molten metal, so that the die casting temperature can be lowered in rheocasting or thixocasting, thereby ensuring an extended lifespan of the die. In addition, when a semi-solid or semi-molten metallic slurry is extruded through a cylinder, turbulence is less likely to occur, and less air is incorporated during casting, thereby preventing formation of air pockets in final products. Besides, the use of semi-solid or semi-molten metallic slurries leads to reduced shrinkage during solidification, improved working efficiency, mechanical properties, and anti-corrosion, and lightweight products. Therefore, such semi-solid or semi-molten metallic slurries can be used as new materials in the fields of automobiles, airplanes, and electrical, electronic information communications equipment.

[0005] As described above, thixocasting starts with billets manufactured by rheocasting. In conventional rheocasting, molten metal is stirred at a temperature of lower than the liquidus temperature while cooling, to break up dendritic structures into spherical particles suitable for rheocasting, for example, by mechanical stirring, electromagnetic stirring, gas bubbling, low-frequency, high-frequency, or electromagnetic wave vibration, electrical shock agitation, etc.

[0006] As an example, U.S. Patent No. 3,948,650 discloses a method and apparatus for manufacturing a liquid-solid mixture. In this method, molten metal is vigorously stirred while cooled to be solidified. A semi-solid metallic slurry manufacturing apparatus disclosed in this patent uses a stirrer to induce flow of the solid-liquid mixture having a predetermined viscosity to break up dendritic crystalline structures or disperse broken dendritic crystalline structures in the liquid-solid mixture. In this method, dendritic crystalline structures formed during cooling are broken up and used as nuclei for spherical particles. However, due to generation of latent heat of solidification at the early stage of cooling, the method causes problems of low cooling rate, manufacturing time increase, uneven temperature distribution in a mixing vessel, and non-uniform crystalline structure. Mechanical stirring applied in the semi-solid metallic slurry manufacturing apparatus inherently leads to non-uniform temperature distribution in the mixing vessel. In addition, the apparatus is operated in a chamber, thereby making it difficult to continuously perform subsequent processes. .

[0007] U.S. Patent No. 4,465,118 discloses a method and apparatus for manufacturing a semi-solid alloy slurry. This apparatus includes a coiled electromagnetic field application portion, a cooling manifold, and a vessel, which are sequentially formed inward, wherein molten metal is continuously loaded down into the vessel, and cooling water is flowed through the cooling manifold to cool the outer wall of the vessel. In manufacturing a semi-solid alloy slurry, molten metal is injected through a top opening of the vessel and cooled by the cooling manifold, thereby resulting in a solidification zone in the vessel. Cooling is sustained while a magnetic field is applied by the electromagnetic field application portion to break up dendritic crystalline structures formed in the solidification zone and to pull an ingot from the slurry through a lower end of the apparatus. The basic technical idea of this method and apparatus is to break up dendritic crystalline structures after solidification by applying vibration. However, many problems, such as complicated processing and non-uniform particle structure, arise with this method. In the manufacturing apparatus, since molten metal is continuously supplied downward to grow an ingot, it is difficult to control the state of the metal ingot and the overall process. Moreover, the vessel is cooled using water prior to applying an electromagnetic field, so that there is a great temperature difference between the peripheral and core regions of the vessel.

[0008] Other types of rheocasting and thixocasting described later are available. However, all of the meth-

ods are based on the technical idea of breaking up dendritic crystalline structures after formation, to generate nuclei of spherical particles, and arise such problems described in conjunction with the above patents.

[0009] U. S. Patent No. 4,694,881 discloses a method for manufacturing thixotropic materials. In this method, an alloy is heated to a temperature at which all metallic components of the alloy are present in a liquid phase, and the resulting molten metal is cooled to a temperature between its liquidus and solidus temperatures. Then, the molten metal is subjected to a sufficient shearing force to break dendritic structures formed during the cooling of the molten metal, so that thixotropic materials are manufactured.

[0010] Japanese Patent Laid-open Application No. 11-33692 discloses a method for producing a metallic slurry for rheocasting. In this method, a molten metal is supplied into a vessel at a temperature near its liquidus temperature or 50°C above its liquidus temperature. Next, when at least a portion of the molten metal reaches a temperature lower than the liquidus temperature, i. e., the molten metal is cooled below a liquidus temperature range, the molten metal is subjected to a force, for example, ultrasonic vibration. Finally, the molten metal is slowly cooled into a metallic slurry, for rheocasting, containing spherical particles. This method also uses a physical force, such as ultrasonic vibration, to break up the dendrites grown at the early stage of solidification. In this method, if the casting temperature is greater than the liquidus temperature, it is difficult to form spherical particle structures and to rapidly cool the molten metal. Furthermore, this method leads to a non-uniformity of surface and core structures.

[0011] Japanese Patent Laid-open Application No. 10-128516 discloses a casting method of thixotropic metal. This method involves loading a molten metal into a vessel and vibrating the molten metal using a vibrating bar dipped in the molten metal to directly transfer its vibrating force to the molten metal. A molten alloy containing nuclei, which is a semi-solid and semi-liquid state, at temperatures lower than its liquidus temperature is formed and cooled to a temperature at which it has a predetermined liquid fraction and held from 30 seconds to 60 minutes to allow nuclei in the molten alloy to grow larger, thereby resulting in thixotropic metal. This method provides relatively large particles of about 100μm and takes a considerably long processing time, and cannot be performed in a larger vessel than a predetermined size.

[0012] U.S. Patent No. 6,432,160 discloses a method for making a thixotropic metal slurry. This method involves simultaneously controlling the cooling and the stirring of molten metal to form a thixotropic metal slurry. In particular, after loading a molten metal into a mixing vessel, a stator assembly positioned around the mixing vessel is operated to generate a magnetomotive force sufficient to stir the molten metal in the vessel rapidly. Next, the temperature of the molten metal is rapidly dropped by means of a thermal jacket equipped around the mixing vessel for precise control of the temperature of the mixing vessel and the molten metal. The molten metal is continuously stirred during cooling cycle in a controlled manner. When the solid fraction of the molten metal is low, high stirring rate is provided. As the solid fraction increases, a greater magnetomotive force is applied.

[0013] Most of the above-described conventional methods and apparatuses for manufacturing semi-solid metal slurries use shear force to break dendritic structures into spherical structures during a cooling process. Since a force such as vibration is applied after the temperature of at least a portion of the molten metal drops below its liquidus temperature, latent heat is generated due to the formation of initial solidification layers. As a result, there are many disadvantages such as reduced cooling rate and increased manufacturing time. In addition, due to a non-uniform temperature between the inner wall and the center of the vessel, it is difficult to form fine, uniform spherical metal particles. This structural non-uniformity of metal particles will be greater if the temperature of the molten metal loaded into the vessel is not controlled.

SUMMARY OF THE INVENTION

[0014] The present invention provides a method and apparatus for manufacturing billets for thixocasting that have a fine, uniform, spherical particle structure, with improvements in energy efficiency and mechanical properties, cost reduction, convenience of casting, and shorter manufacturing time.

[0015] The present invention provides a method and apparatus for manufacturing high quality billets for thixocasting in a continuous manner.

[0016] In accordance with an aspect of the present invention, there is provided a method of manufacturing billets for thixocasting, the method comprising: (a) applying an electric field to a domain of a sleeve defined by first and second plungers inserted through each end of the sleeve and loading a molten metal into the domain of the sleeve to form a semi-solid metallic slurry; (b) moving the first plunger toward the second plunger to compress the semi-solid metallic slurry and form a billet via cooling; and (c) shifting the billet toward the second plunger to discharge the billet from the sleeve.

[0017] Another method of manufacturing billets for thixocasting according to the present invention may comprise, after step (b), (c') shifting the billet toward the second plunger and moving the first plunger backward to allow for a domain between the billet and the first plunger that is the same in size as the domain initially defined between the first and second plungers and repeating steps (a) and (b) to continuously form another billet, wherein step (c') is repeated to continuously form a number of billets.

[0018] According to specific embodiments of the

above methods according to the present invention, applying the electromagnetic field to the domain may be performed prior to, at the start, or in the middle of loading the molten metal into the sleeve. Applying the electromagnetic field to the sleeve may be sustained until the molten metal in the domain of the sleeve has a solid fraction of 0.001-0.7, preferably, 0.001-0.4, more preferably, 0.001-0.1.

[0019] An alternatively method of manufacturing billets for thixocasting according to the present invention may further comprise cooling the molten metal after loading into the domain under the electromagnetic field. Cooling the molten metal may be sustained until the molten metal in the domain has a solid fraction of 0.1-0.7, for example, at a rate of 0.2-5.0°C/sec, preferably, 0.2-2.0°C/sec.

[0020] In accordance with another embodiment of the present invention, there is provided an apparatus for manufacturing billets for thixocasting, the apparatus comprising: a stirring unit which includes a space and applies an electromagnetic field to the space; a sleeve which extends across the space of the stirring unit and includes a domain into which a molten metal is loaded; a first plunger which is inserted through an end of the sleeve to form a sidewall of the domain of the sleeve and is moved to compress a semi-solid slurry manufactured in the domain; and a second plunger which is inserted through the other end of the sleeve to form the other sidewall of the domain of the sleeve and which is kept in place when the first plunger is moved to compress the slurry and is moved backward after a billet having a predetermined size has been fomed as a result of the compression.

[0021] In an apparatus for manufacturing billets for thixocasting according to the present invention, the sleeve may comprise a billet discharge hole in its lower surface a predetermined distance away from the domain toward the second plunger.

[0022] According to specific embodiments of the present invention, the stirring unit may apply the electromagnetic field prior to, at the start, or in the middle of loading the molten metal into the sleeve. The stirring unit may apply the electromagnetic file until the molten metal in the sleeve has a solid fraction of 0.001-0.7, preferably, 0.001-0.4, more preferably, 0.001-0.1.

[0023] Alternatively, the sleeve of the apparatus may comprise a temperature control element. In this case, the temperature control element may comprise at least one of a cooler and an electrical heater. The temperature control element may cool the molten metal in the sleeve to reach a solid fraction of 0.1-0.7, for example, at a rate of 0.2-5.0°C/sec, preferably, 0.2-2.0°C/sec.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The above and other features and advantages of the present invention will become more apparent by describing in detail exemplary embodiments thereof with reference to the attached drawings in which:

FIG. 1 is a graph of temperature profile applied in manufacturing billets for thixocasting according to the present invention;
FIGS. 2 through 7 illustrate the structure and the operation of an apparatus for manufacturing billets for thixocasting according to an embodiment of the present invention; and
FIGS. 8 through 10 illustrate the structure and the operation of an apparatus for manufacturing billets for thixocasting according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[0025] The preset invention will be described more fully in the following exemplary embodiments of the invention with reference to the accompanying drawings.

[0026] Billets used in thixocasting are manufactured by rheocasting. Therefore, a manufacturing method of billets for thixocasting according to the present invention is based on rheocasting. The manufacturing method of billets for thixocasting, in other words, a rheocasting method, according to the present invention will be described with reference to FIG. 1.

[0027] Unlike the above-described conventional techniques, a rheocasting method according to the present invention involves manufacturing a semi-solid metallic slurry from a molten metal in a sleeve and applying pressure to the semi-solid metallic slurry to form billets of a predetermined size. In particular, according to the present invention, an electromagnetic field is applied prior to the completion of loading the molten metal into the sleeve, so as to stir the molten metal. In other words, electromagnetic stirring is performed prior to, at the start, or in the middle of loading the molten metal into the sleeve, to prevent formation of dendritric structures. Ultrasonic waves instead of the electromagnetic field can be applied for stirring.

[0028] In particular, an empty sleeve is located in a space of a manufacturing apparatus. An electromagnetic field is applied to a predetermined slurry manufacturing domain of the sleeve. The intensity of the applied electromagnetic field is strong enough to stir molten metal.

[0029] FIG. 1 is a graph of temperature profile applied in manufacturing billets for thixocasting according to the present invention. As shown in FIG. 1, molten metal is loaded into the sleeve at a temperature Tp. As described above, the molten metal may be loaded into the sleeve after applying an electromagnetic field to the sleeve. However, the present invention is not limited to this, and electromagnetic stirring may be performed at the start or in the middle of loading the molten metal into the sleeve.

[0030] Due to the electromagnetic stirring initiated prior to the completion of loading molten metal into the slur-

ry, the molten metal does not grow into dendritic structures near the inner wall of the sleeve at the early stage of solidification, and numerous micronuclei are concurrently generated throughout the sleeve because the temperature of the entire molten metal rapidly drops to a temperature lower than its liquidus temperature.

[0031] Applying an electromagnetic field to the sleeve prior to or at the start of loading molten metal into the sleeve leads to active stirring of the molten metal at the center and the inner wall regions of the sleeve and rapid heat transfer throughout the entire molten metal in the sleeve, thereby suppressing the formation of solidification layers near the inner wall of the sleeve at the early stage of cooling. In addition, such active stirring of the molten metal induces smooth convection heat transfer between the higher temperature molten metal and the lower temperature inner sleeve wall, so that the entire molten metal can be cooled rapidly. Due to the electromagnetic stirring, particles in the molten metal scatter upon loading into the sleeve and disperse throughout the sleeve as nuclei, so that there is rare a temperature difference throughout the sleeve during cooling. However, in conventional techniques where molten metal is stirred after the completion of loading into a sleeve, the temperature of the molten metal suddenly drops as soon as it contacts the low temperature inner sleeve wall, so that dendritic crystals grow from solidification layers formed near the inner slurry vessel wall at the early stage of cooling.

[0032] The principles of the present invention will become more apparent when described in connection with latent heat of solidification. In a rheocasting method according to the present invention, molten metal does not solidify near the inner sleeve wall at the early stage of cooling, and no latent heat of solidification is generated. Accordingly, the amount of heat to be dissipated from the molten metal for cooling is equivalent only to the specific heat of the molten metal that corresponds to about 1/400 of the latent heat of solidification. Therefore, dendrites, which are generated frequently near the inner sleeve wall at the early stage of cooling when using conventional methods, are not formed, and the entire molten metal throughout the sleeve can be uniformly cooled. It takes merely about 1-10 seconds from the loading of the molten metal. As a result, numerous nuclei are created and disperse uniformly throughout the entire molten metal in the sleeve. The increased density of nuclei shortens the distance between the nuclei, and spherical particles instead of dendritic particles are grown.

[0033] The same effects can be achieved even when an electromagnetic field is applied in the middle of loading the molten metal into the sleeve. In other words, solidification layers are hardly formed near the inner sleeve wall even when electromagnetic stirring begins in the middle of loading the molten metal into the sleeve.

[0034] It is preferable that the temperature, Tp, of the molten metal be maintained in a range from its liquidus temperature to 100°C above the liquidus temperature (melt superheat = 0~100°C) at the time of being loaded into the sleeve. According to the present invention, since the entire sleeve containing the molten metal is cooled uniformly, it allows for the loading of the molten metal into the sleeve at a temperature of 100°C above its liquidus temperature, without the need to cool the temperature of the molten metal to near its liquidus temperature.

[0035] On the other hand, in conventional methods, an electromagnetic field is applied to a slurry vessel after the completion of loading molten metal into the slurry vessel and a portion of the molten metal has reached below its liquidus temperature. Accordingly, latent heat is generated due to the formation of solidification layers near the inner wall of the vessel at the early stage of cooling. Because the latent heat of solidification is about 400 times greater than the specific heat of the molten metal, it takes much time to drop the temperature of the entire molten metal below its liquidus temperature. Therefore, in these conventional methods, the molten metal is loaded into the vessel after the molten metal has cooled to a temperature near its liquidus temperature or to a temperature of 50°C above its liquidus temperature. However, in practice, controlling the overall manufacturing procedure is not easy when there is such a need to wait for a temperature drop of the molten metal to a predetermined level.

[0036] According to the present invention, the electromagnetic stirring may be stopped at any point after at least a portion of the molten metal in the sleeve reaches a temperature lower than its liquidus temperature T_l, i. e., after nuclei are created in the molten metal at a solid fraction of about 0.001, as illustrated in FIG. 1. For example, an electromagnetic field may be applied to the sleeve throughout all processes of loading molten metal into the sleeve, cooling the molten metal into a semi-solid slurry, and applying pressure to form billets. This is because, once nuclei are distributed uniformly throughout a slurry manufacturing domain of the sleeve, the electromagnetic stirring does not affect the growth of crystalline particles from the nuclei in the metallic slurry.

[0037] Therefore, the electromagnetic stirring can be sustained only during the manufacture of the metallic slurry, until the solid fraction of the molten metal reaches at least 0.001-0.7. However, the electromagnetic stirring may be sustained until the solid fraction of the molten metal in the sleeve manufacturing domain of the sleeve reaches the range of, preferably, 0.001-0.4, more preferably, 0.001-0.1, for energy efficiency.

[0038] After loading a molten metal into the slurry manufacturing domain of the sleeve and allowing nucleation of a uniform distribution in the molten metal, the slurry manufacturing domain is cooled to accelerate the growth of the nuclei. This cooling may be concurrent with the loading of the molten metal into the slurry manufacturing domain. As described above, the electromag-

netic stirring may be sustained throughout all the cooling process.

[0039] Alternatively, the cooling process may be sustained throughout the formation of billets from a resulting semi-solid metallic slurry by applying pressure, preferably, sustained until the molten metal has a solid fraction of 0.1-0.7, this point of time being denoted as t_2 in FIG. 1. In this case, the molten metal may be cooled at a rate of 0.2-5.0°C/sec. However, the cooling rate of the molten metal may be varied in the range of 0.2-2.0°C/sec depending on a desired nuclei distribution and granularity.

[0040] Immediately after the manufacture of a semi-solid metallic slurry having a predetermined solid fraction according to the above-described method, the semi-solid metallic slurry is processed by applying pressure and cooling to form billets for thixocasting.

[0041] In the above-described method according to the present invention, a semi-solid metallic slurry can be manufactured within a short time, merely in 30-60 seconds from loading the molten metal into the sleeve for a metallic slurry with a solid fraction of 0.1-0.7. In addition, billets having a uniform, dense spherical particle structure can be manufactured from the semi-solid metallic slurry formed by the method.

[0042] An apparatus for manufacturing billets for thixocasting based on the above-described rheocasting method according to an embodiment of the present invention will be described with reference to FIGS. 2 through 7.

[0043] Referring to FIG. 2, an apparatus for manufacturing billets for thixocasting according to an embodiment of the present invention includes a stirring unit 1 having a space 11 and coiled electromagnetic field application portions 12 and 13 arranged around the space 11; a sleeve 2 extending across the space 11 of the stirring unit 1; a first plunger 3 inserted into an end of the sleeve 2; and a second plunger 4 inserted into the other end of the sleeve 2.

[0044] In the stirring unit 1, the space 11 and the coiled electromagnetic field application portions 12 and 13 are fixed by means of a frame (not shown). The coiled electromagnetic field application portions 12 and 13 emanate a predetermined intensity of electromagnetic field towards the space 11 so as to stir the molten metal loaded into the sleeve 2 and is electrically connected to a controller (not shown) which controls the intensity of the electromagnetic field generated by the coiled electromagnetic field application portions 12 and 13, their operating duration, etc. Any coiled apparatus for electromagnetic stirring may be used for the coiled electromagnetic field application portions 12 and 13 without limitations. In addition, the stirring unit 1 may be implemented to be able to apply ultrasonic waves, instead of the electromagnetic field, for stirring.

[0045] As shown in FIG. 2, the coiled electromagnetic field application portions 12 and 13 apply an electric field to the sleeve 2, in particular, to a slurry manufacturing domain 21 of the sleeve 2 and a slurry funnel 23 formed to extend above a slurry loading hole 22 of the sleeve 2. Alternatively, the upper coiled electromagnetic field application portion 12 may be formed to a height that corresponds to the height of the slurry funnel 23. Accordingly, molten metal can be thoroughly stirred prior to being loaded into the sleeve 2.

[0046] As described above, the application of the electromagnetic field may be sustained throughout all processes, even when a semi-solid slurry is compressed to form billets. However, the application of the electromagnetic field may be sustained up to the manufacture of the semi-solid slurry, for example, sustained until the solid fraction of the molten metal reaches at least 0.001-0.7, preferably 0.001-0.4, more preferably 0.001-0.1, for energy efficiency. The duration of applying the electromagnetic field can be experimentally determined for practical application.

[0047] In the billet manufacturing apparatus according to the present invention, the sleeve 2 serves as a slurry vessel in which a semi-solid metallic slurry is manufactured from molten metal with electromagnetic field stirring and as a mold for manufacturing billets. As described above, electromagnetic stirring must be initiated prior to the completion of loading molten metal into the sleeve 2.

[0048] The first plunger 31 is inserted into an end of the sleeve 2, and the second plunger 32 is inserted into the other end of the sleeve 2. The first plunger 31 and the second plunger 32 are separated a predetermined distance from one another with the slurry manufacturing domain 21 therebetween. In other words, the first plunger 31 and the second plunger 32 form the sidewalls of the slurry manufacturing domain 21. An electromagnetic field is applied to the slurry manufacturing domain 21 by the stirring unit 1, and a molten metal is loaded into the slurry manufacturing domain 21 via a loading unit 4, such as a ladle. The slurry loading hole 22 is formed on the top of the sleeve 2. The slurry funnel 23 extends from the slurry loading hole 22 to above the stirring unit 1 so as to make it easier to pour molten metal from the loading unit 4 via the slurry loading hole 21 into the sleeve 2.

[0049] The sleeve 2 may be made of a metallic material or an insulating material, such as alumina or aluminum nitride. For a metallic sleeve 2, a metal having a higher melting point than the molten metal to be loaded therein is preferable. Although not illustrated in FIG. 2, a thermocouple may be installed in the sleeve 2 connected to the controller (not shown) to provide temperature information on the sleeve 2 to the controller.

[0050] In an alternative embodiment, the sleeve 2 may comprise a temperature control element 25, as illustrated in FIG. 2. The temperature control element 25 may be comprised of a cooler and/or a heater. A preferred example of a cooler may be a cooling water pipe 26 embedded in a support block 27 to be able to surround the sleeve 2, like a water jacket, as shown in FIG. 2. An additional heater (not shown), for example, an

electrical heater, may be externally disposed near the sleeve 2. A coiled electrical heater may be used. It is obvious that a thermocouple (not shown) can be installed in the sleeve 2. Although the temperature control element 25 in FIG. 2 is illustrated as being over the entire sleeve 2, the temperature control element 25 may be formed only in a limited area near the slurry manufacturing domain 21.

[0051] The molten metal loaded in the sleeve 2 can be cooled at an appropriate rate by the temperature control element 25 until the molten metal reaches a solid fraction of 0.1-0.7. The cooling rate may be controlled to be 0.2-5°C/sec, preferably, 0.2-2°C/sec. As described above, cooling may be performed after or during electromagnetic stirring or at the start of loading molten metal into the sleeve 2. In forming billets from a resulting semi-solid slurry by applying pressure and cooling, the cooling rate may be raised by the temperature control element 25.

[0052] The first plunger 31 and the second plunger 32 inserted into each end of the sleeve 2 are connected to separate cylindrical pressing apparatuses (not shown) to be able to reciprocate forward and backward like a piston. The first plunger 31 is kept in place and forms a sidewall of the slurry manufacturing domain 21 during the application of an electromagnetic field and the cooling of molten metal to form a semi-solid slurry and is moved forward to compress the semi-solid slurry after formation. The second plunger 32 is kept in place to form the other sidewall of the slurry manufacturing domain 21 during the manufacture of the semi-solid slurry and when the semi-solid slurry is compressed by the first plunger 31 to form a billet of a predetermined size. The first plunger 31 is moved backward to allow for room for the slurry manufacturing domain 21.

[0053] Next, a process of manufacturing billets for thixocasting in the above-described apparatus according to an embodiment of the present invention will be described with reference to FIGS. 1 through 7.

[0054] Initially, the coiled electromagnetic field application portions 12 and 13 of the stirring unit 1, shown in FIG. 2, apply an electromagnetic field having a predetermined frequency to the space 11 at a predetermined intensity. As a nonlimiting example, the coiled electromagnetic field application portions 12 and 13 may apply a 60-Hz electromagnetic field at a voltage of 250V and an intensity of 500 Gauss.

[0055] In this state, a molten metal prepared in a separate furnace (not shown) is transferred into the loading unit 5, for example, a ladle, and loaded into the slurry manufacturing domain 21 of the sleeve 2 under the electromagnetic field. Alternatively, the furnace may be connected to the sleeve 2 to allow direct loading of molten metal into the sleeve 2. As described above, the molten metal can be loaded into the sleeve 2 at a temperature of 100°C above its liquidus temperature, Prior to the loading of the molten metal into the slurry manufacturing domain 21, which is formed in the sleeve 2 by the first plunger 31 and the second plunger 32, inert gas, such as N_2, Ar, etc., is supplied via a gas inlet 24 into the slurry manufacturing domain 21 in order to prevent oxidation of the molten metal.

[0056] When truly molten metal is loaded into the slurry manufacturing domain 21 of the sleeve 2 under electromagnetic stirring, fine particles are uniformly distributed over the slurry manufacturing domain 21 and grow fast without forming dendritic structures.

[0057] Alternatively, the electromagnetic field may be applied at the start or in the middle of loading the molten metal into the sleeve 2, as described above.

[0058] In addition, the application of the electromagnetic field may be sustained throughout the formation of billets, as described above. However, the application of the electromagnetic field may be sustained until the solid fraction of the molten metal reaches at least 0.001-0.7, preferably 0.001-0.4, more preferably 0.001-0.1, for energy efficiency. The duration of applying the electromagnetic field can be experimentally determined for practical application.

[0059] After the termination of applying the electromagnetic field or during the application of the electromagnetic field, the molten metal in the sleeve 2 is cooled at a predetermined rate into a semi-solid metallic slurry 51 having a solid fraction of 0.1-0.7. The cooling rate is controlled by the temperature control element 25, i.e., cooling water flowing in the cooling water pipe 26, installed on the outer wall of the sleeve 2, for example, to be 0.2-5°C/sec, preferably, 0.2-2°C/sec. The duration of cooling, in other words, the point of time being denoted as t_2 in FIG. 1, for a solid fraction of 0.1-0.7 is experimentally determined.

[0060] After the manufacture of the semi-solid metallic slurry 51 is completed, the second plunger 32 in a state of being fixed in the sleeve 2, the first plunger 31 is pushed toward the second plunger 32 to form a first billet 52 having a predetermined size, as shown in FIG. 3, followed by rapid cooling at a higher rate using cooling water.

[0061] After the formation of the first billet 52, the first plunger 31 is further pushed toward the second plunger 32 to shift both the second plunger 32 and the first billet 52, as shown in FIG. 4. Alternatively, the second plunger 32 may be shifted separately from the first billet 53, not by the force of the first plunger 31.

[0062] The shifting distance of the second plunger 32 and the first billet 52 is determined such that the end of the first billet 53 close to the first plunger 31 reaches the initial position of the end of the second plunger 52 facing the first plunger 52. This is to allow the shifted first billet 52 to form the slurry manufacturing domain 21 together with the first plunger 31 for successive billet formation, which will be apparent in FIG. 5.

[0063] Alternatively, forming the first billet 52 as illustrated in FIG. 3 and shifting both the second plunger 52 and the first billet 52 as illustrated in FIG. 4 may be performed as a single step after the manufacture of the

semi-solid metallic slurry as illustrated in FIG. 2. In particular, after the semi-solid metallic slurry has been manufactured, the first plunger 31 is moved by a force that is enough to compress the semi-solid metallic slurry and form the first billet 52, while the second plunger 32 is moved backward keeping pace with the first plunger 31. In this case, the first billet 52 is shifted out of the slurry manufacturing domain 21 under an electromagnetic field during manufacture.

[0064] After the second plunger 32 and the first billet 52 have been shifted, the first plunger 31 is returned to its initial position to allow for the slurry manufacturing domain 21 between the first plunger 31 and the first billet 52, as shown in FIG. 5. Next, a semi-solid metallic slurry 51 for another billet is manufactured in the slurry manufacturing domain 21 through the above-described electromagnetic stirring and cooling processes according to the temperature profile of FIG. 1. Next, the semi-solid metallic slurry 51 is compressed by the first plunger 31 to form a second billet 53 having a predetermined size, as shown in FIG. 6. The second plunger 32, the first billet 53, and the second billet 53 are shifted by the first plunger 31, and the first plunger 31 is returned to its initial position to form the slurry manufacturing domain 21 again, as illustrated in FIG. 7. Additional billets can be successively formed through the above-described processes.

[0065] In the above-described method and apparatus for manufacturing billets for thixocasting according to the present invention, a number of quality billets can be manufactured in a continuous manner. In this case, adjacent billets are likely to adhere to one another due to melting but can be easily separated. The number of billets may be discharged after the second plunger 32 is removed from the sleeve 2. Alternatively, the manufactured billets may be discharged through an additional discharge hole formed in the sleeve 2.

[0066] FIGS. 8 through 10 illustrate the structure and the operation of an apparatus for manufacturing billets for thixocasting according to another embodiment of the present invention, which differs from the previous embodiment in that each billet is discharged from the sleeve right after manufacture, instead of being discharged at a time following the successive manufacture of a number of billets. The following description will be focused on this difference from the previous embodiment.

[0067] The basic structure of the apparatus of FIG. 8 is the same as that of the apparatus described in the previous embodiment. However, the apparatus of FIG. 8 further comprises a billet discharge hole 28 in the sleeve 2 a predetermined distance apart away from the slurry manufacturing domain 21 toward the second plunger 32. The size of the billet discharge hole 28 may correspond to the size of the billet. However, it is preferable that the billet discharge hole 28 is determined to be large enough to discharge various sizes of billets. In this embodiment, the temperature control element 25 is designed not to cover the billet discharge hole 28 and not to affect billets discharged from the sleeve 2.

[0068] Next, a process of manufacturing billets for thixocasting in the above apparatus described with reference to FIGS. 8 through 10 according to an embodiment of the present invention will be described.

[0069] Initially, the coiled electromagnetic field application portions 12 and 13 of the stirring unit 1, shown in FIG. 8, apply an electromagnetic field to the space 11. In this state, a molten metal is loaded via the loading unit 5, for example, a ladle, into the sleeve 2 under the electromagnetic field. Here, the molten metal may be directly loaded from a furnace where the molten metal is manufactured into the sleeve 2, as described above. Obviously, the molten metal can be loaded into the sleeve 2 at a temperature of 100°C above its liquidus temperature, Prior to the loading of the molten metal into the slurry manufacturing domain 21, which is formed in the sleeve 2 by the first plunger 31 and the second plunger 32, inert gas, such as N_2, Ar, etc., is supplied via the gas inlet 24 into the slurry manufacturing domain 21 in order to prevent oxidation of the molten metal.

[0070] Alternatively, the electromagnetic field may be applied at the start or in the middle of loading the molten metal into the slurry manufacturing domain 21, as described above.

[0071] The loading of the molten metal is followed by cooling at a predetermined rate to form a semi-solid metallic slurry 51 having a solid fraction of 0.1-0.7. The cooling rate is controlled by the temperature control element 25, i.e., cooling water flowing in the cooling water pipe 26, installed on the outer wall of the sleeve 2, for example, to be 0.2-5°C/sec, preferably, 0.2-2°C/sec. In addition, the application of the electromagnetic field may be sustained throughout all the manufacturing processes, as described above. However, the application of the electromagnetic field may be sustained until the solid fraction of the molten metal reaches at least 0.001-0.7, preferably 0.001-0.4, more preferably 0.001-0.1, for energy efficiency.

[0072] After the manufacture of the semi-solid metallic slurry 51 is completed, the second plunger 32 in a state of being fixed in the sleeve 2, the first plunger 31 is pushed toward the second plunger 32 to form a billet 54 having a predetermined size, as shown in FIG. 9, followed by cooling.

[0073] After the formation of the billet 54, the first plunger 31 is further pushed toward the second plunger 32 to discharge the billet 54 through the billet discharge hole 28. At this time, the second plunger 32 is also shifted backward by the force of the first plunger 31. Alternatively, the second plunger 32 may be shifted separately from the billet 54, not by the force of the first plunger 31.

[0074] After the discharge of the billet 54 from the sleeve 2, the first plunger 31 and the second plunger 32 are returned to their initial position to define the slurry manufacturing domain 21 for another billet therebe-

tween. Next, the processes described with reference to FIGS. 8 through 10 are repeated many times to manufacture a number of billets with a fine, uniform, spherical particle structure, wherein each billet is discharged after manufacture, through the billet discharge hole 28. In this embodiment, comparing to the previous embodiment described with reference to FIGS. 2 through 7, billets can be readily applied to a subsequent process with more efficiency, without the need to individually separate billets adhering to one another.

[0075] As described above, a method and apparatus for manufacturing billets for thixocasting according to the present invention are widely applicable to rheocasting and thixocasting with various kinds of metals and alloys, for example, aluminum, magnesium, zinc, copper, iron, and alloys of the forgoing metals.

[0076] The method and apparatus for manufacturing billets for thixocasting according to the present invention provide the following effects.

[0077] First, billets having a uniform, fine, spherical particle structure can be manufactured even with alloys.

[0078] Second, densely populated, uniform spherical particles can be formed with molten metal as a starting material in a short time through electromagnetic stirring initiated at a temperature above the liquidus temperature of a source metal to generate more nuclei throughout the sleeve.

[0079] Third, billets manufactured according to the present invention have improved mechanical properties even when manufactured from alloys.

[0080] Fourth, the duration of electromagnetic stirring is greatly shortened, thereby saving energy for the stirring.

[0081] Fifth, the simplified overall process and the reduced manufacturing duration improve productivity.

[0082] Sixth, numerous bullets can be mass produced successively.

[0083] While the present invention has been particularly shown and described with reference to exemplary embodiments thereof, it will be understood by those of ordinary skill in the art that various changes in form and details may be made therein without departing from the spirit and scope of the present invention as defined by the following claims.

Claims

1. A method of manufacturing billets for thixocasting, the method comprising:

    (a) applying an electric field to a domain of a sleeve defined by first and second plungers inserted through each end of the sleeve and loading a molten metal into the domain of the sleeve to form a semi-solid metallic slurry;
    (b) moving the first plunger toward the second plunger to compress the semi-solid metallic slurry and form a billet via cooling; and
    (c) shifting the billet toward the second plunger to discharge the billet from the sleeve.

2. The method of claim 1, after step (b), comprising (c') shifting the billet toward the second plunger and moving the first plunger backward to allow for a domain between the billet and the first plunger that is the same in size as the domain initially defined between the first and second plungers and repeating steps (a) and (b) to continuously form another billet, wherein step (c') is repeated to continuously form a number of billets.

3. The method of claim 1, wherein applying the electromagnetic field to the domain is performed prior to loading the molten metal into the sleeve.

4. The method of claim 1, wherein applying the electromagnetic field to the domain is performed at the start of loading the molten metal into the sleeve.

5. The method of claim 1, wherein applying the electromagnetic field to the domain is performed in the middle of loading the molten metal into the sleeve.

6. The method of claim 1, wherein applying the electromagnetic field to the sleeve is sustained until the molten metal in the domain of the sleeve has a solid fraction of 0.001-0.7.

7. The method of claim 6, wherein applying the electromagnetic field to the sleeve is sustained until the molten metal in the domain of the sleeve has a solid fraction of 0.001-0.4.

8. The method of claim 7, wherein applying the electromagnetic field to the sleeve is sustained until the molten metal in the domain of the sleeve has a solid fraction of 0.001-0.1.

9. The method of claim 1, further comprising cooling the molten metal after loading into the domain under the electromagnetic field.

10. The method of claim 9, wherein cooling the molten metal is sustained until the molten metal in the domain has a solid fraction of 0.1-0.7.

11. The method of claim 9, wherein cooling the molten metal is performed at a rate of 0.2-5.0°C/sec.

12. The method of claim 9, wherein cooling the molten metal is performed at a rate of 0.2-2.0°C/sec.

13. An apparatus for manufacturing billets for thixocasting, the apparatus comprising:

a stirring unit which includes a space and applies an electromagnetic field to the space;
a sleeve which extends across the space of the stirring unit and includes a domain into which a molten metal is loaded;
a first plunger which is inserted through an end of the sleeve to form a sidewall of the domain of the sleeve and is moved to compress a semi-solid slurry manufactured in the domain; and
a second plunger which is inserted through the other end of the sleeve to form the other sidewall of the domain of the sleeve and which is kept in place when the first plunger is moved to compress the slurry and is moved backward after a billet having a predetermined size has been formed as a result of the compression.

14. The apparatus of claim 13, wherein the sleeve comprises a billet discharge hole in its lower surface a predetermined distance away from the domain toward the second plunger.

15. The apparatus of claim 13, wherein the stirring unit applies the electromagnetic field prior to loading the molten metal into the sleeve.

16. The apparatus of claim 13, wherein the stirring unit applies the electromagnetic field at the start of loading the molten metal into the sleeve.

17. The apparatus of claim 13, wherein the stirring unit applies the electromagnetic field in the middle of loading the molten metal into the sleeve.

18. The apparatus of claim 13, wherein the stirring unit applies the electromagnetic file until the molten metal in the sleeve has a solid fraction of 0.001-0.7.

19. The apparatus of claim 18, wherein the stirring unit applies the electromagnetic field until the molten metal in the sleeve has a solid fraction of 0.001-0.4.

20. The apparatus of claim 19, wherein the stirring unit applies the electromagnetic field until the molten metal in the sleeve has a solid fraction of 0.001-0.1.

21. The apparatus of claim 13, wherein the sleeve comprises a temperature control element.

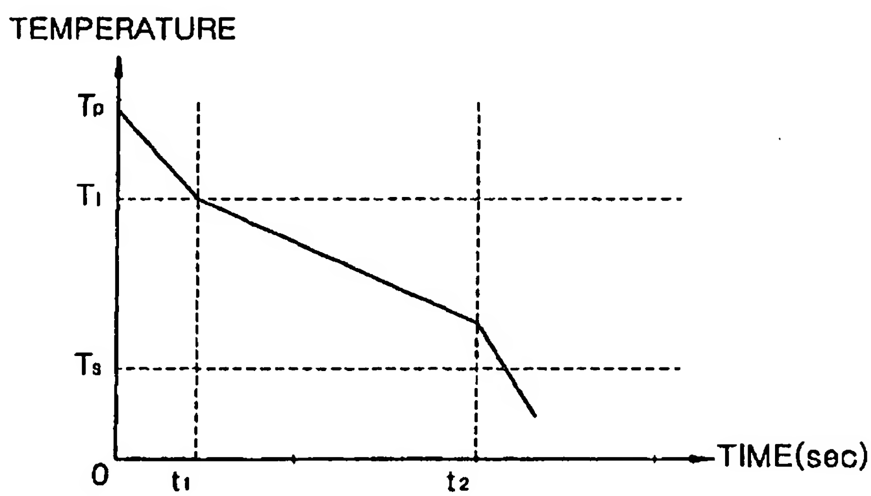
22. The apparatus of claim 21, wherein the temperature control element comprises at least one of a cooler and an electrical heater.

23. The apparatus of claim 21, wherein the temperature control element cools the molten metal in the sleeve to reach a solid fraction of 0.1-0.7.

24. The apparatus of claim 21, wherein the temperature control element cools the molten metal in the sleeve at a rate of 0.2-5.0°C/sec.

25. The apparatus of claim 24, wherein the temperature control element controls the molten metal in the sleeve at a rate of 0.2-2.0°C/sec.

FIG. 1



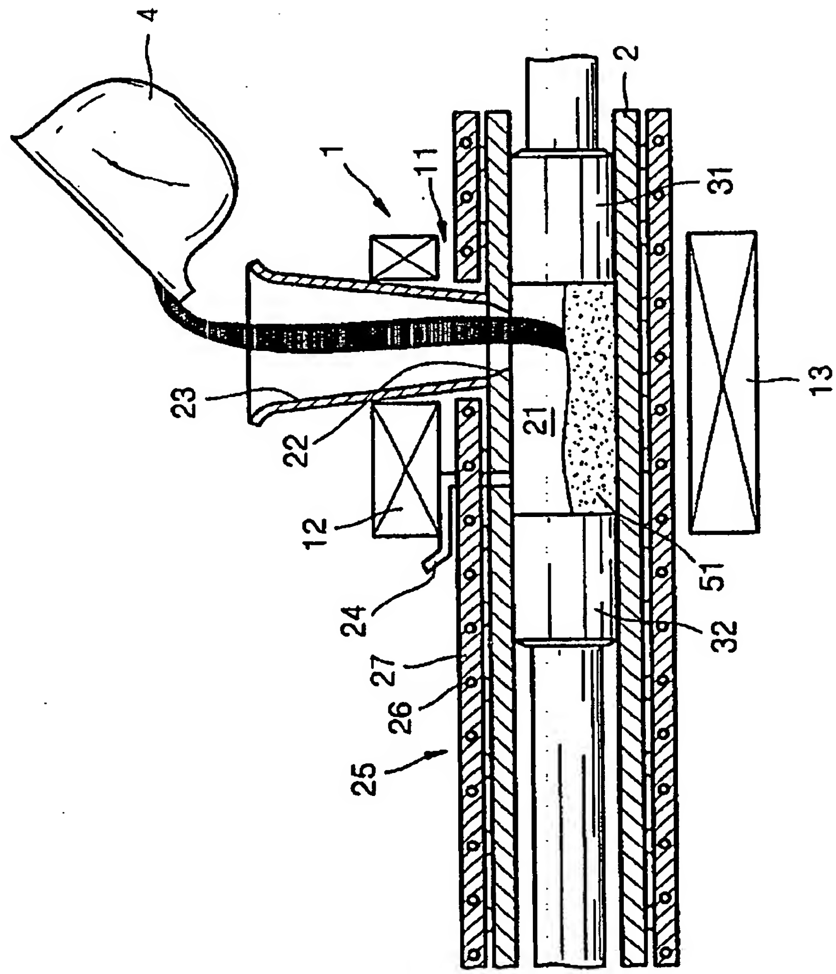


FIG. 2

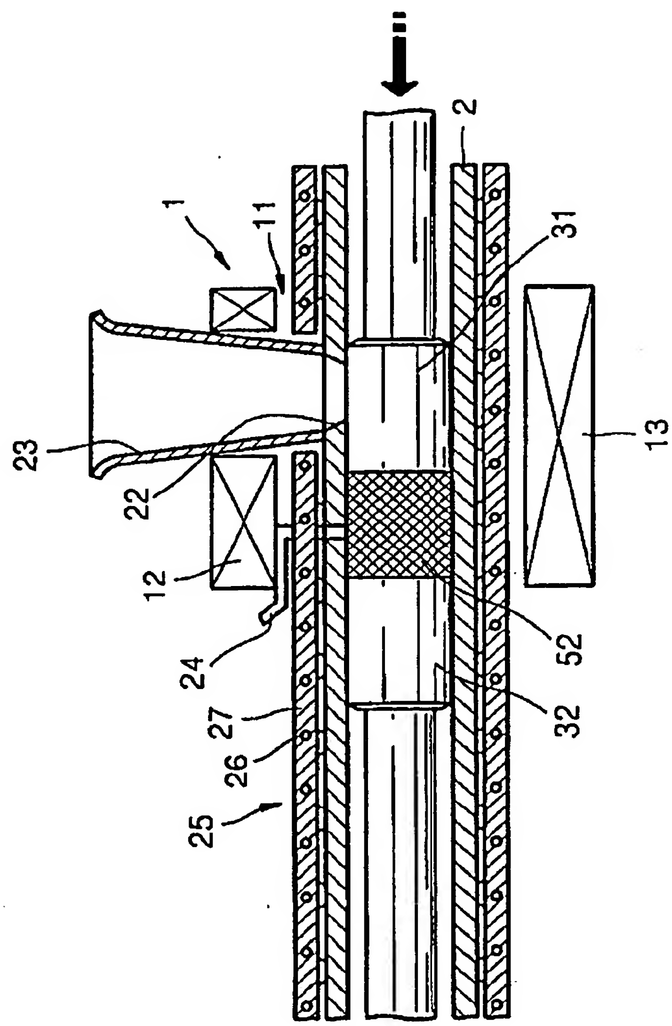


FIG. 3

FIG. 4

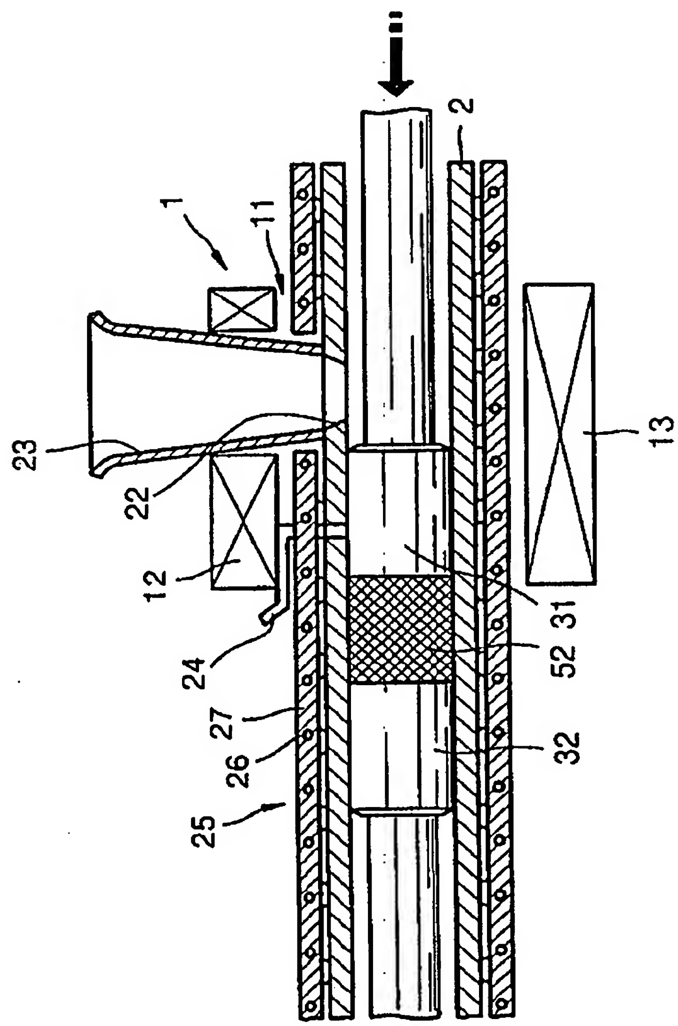


FIG. 5

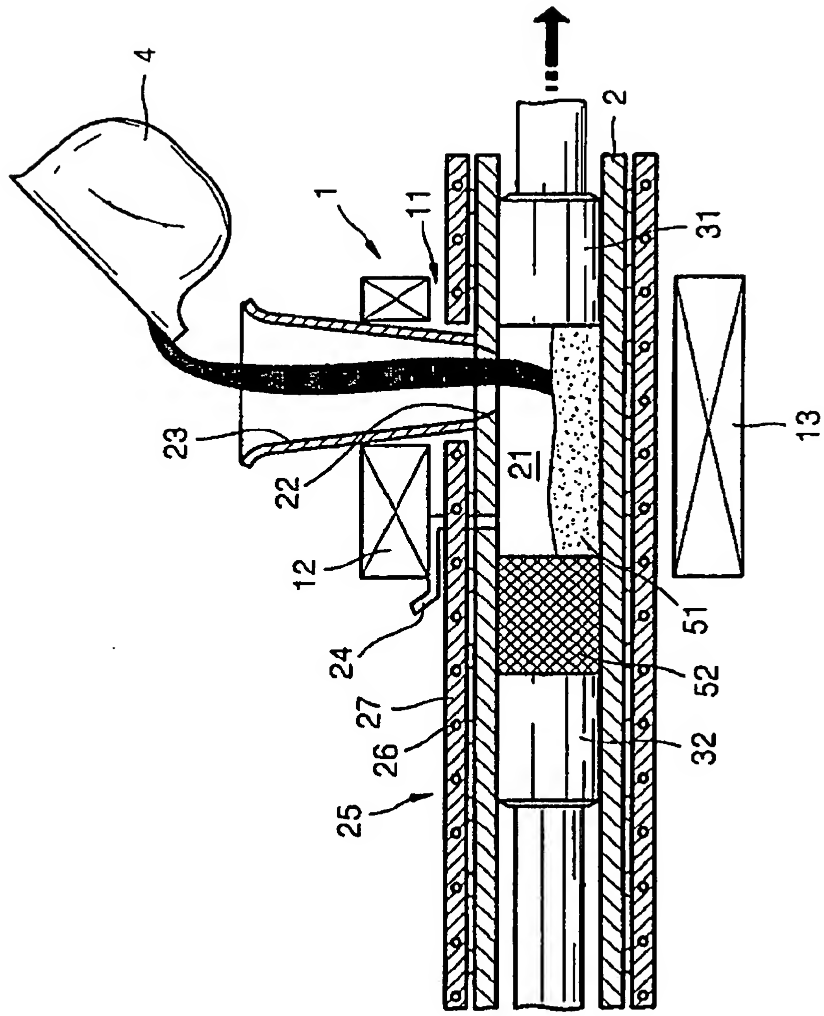


FIG. 6

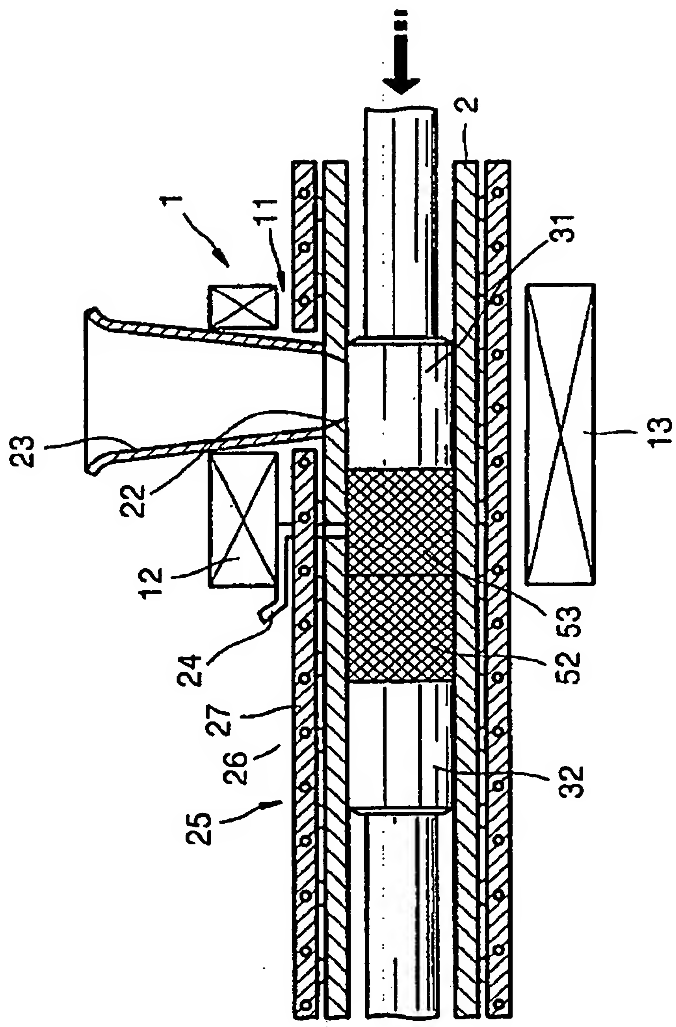


FIG. 7

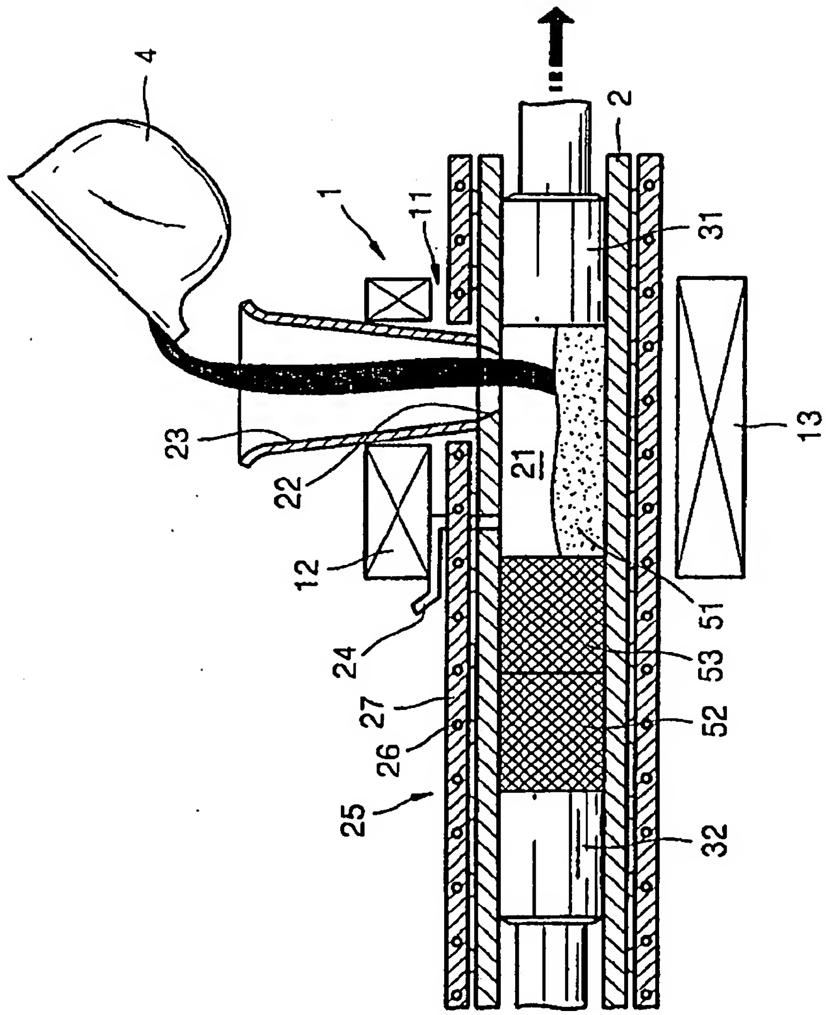


FIG. 8

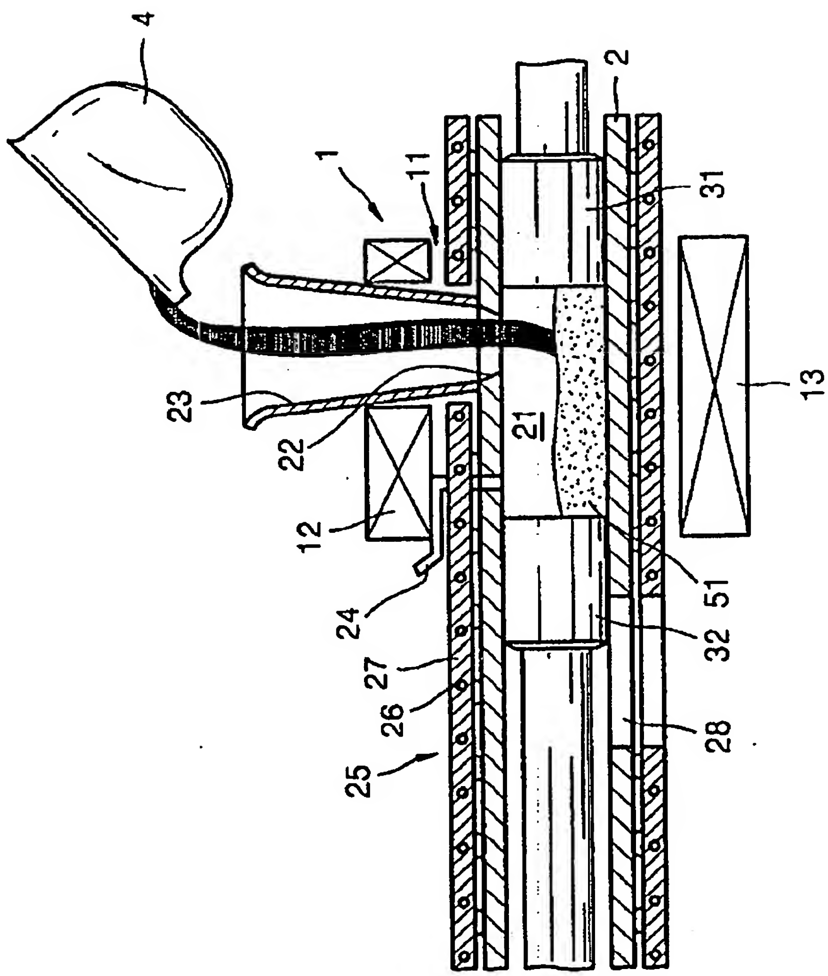


FIG. 9

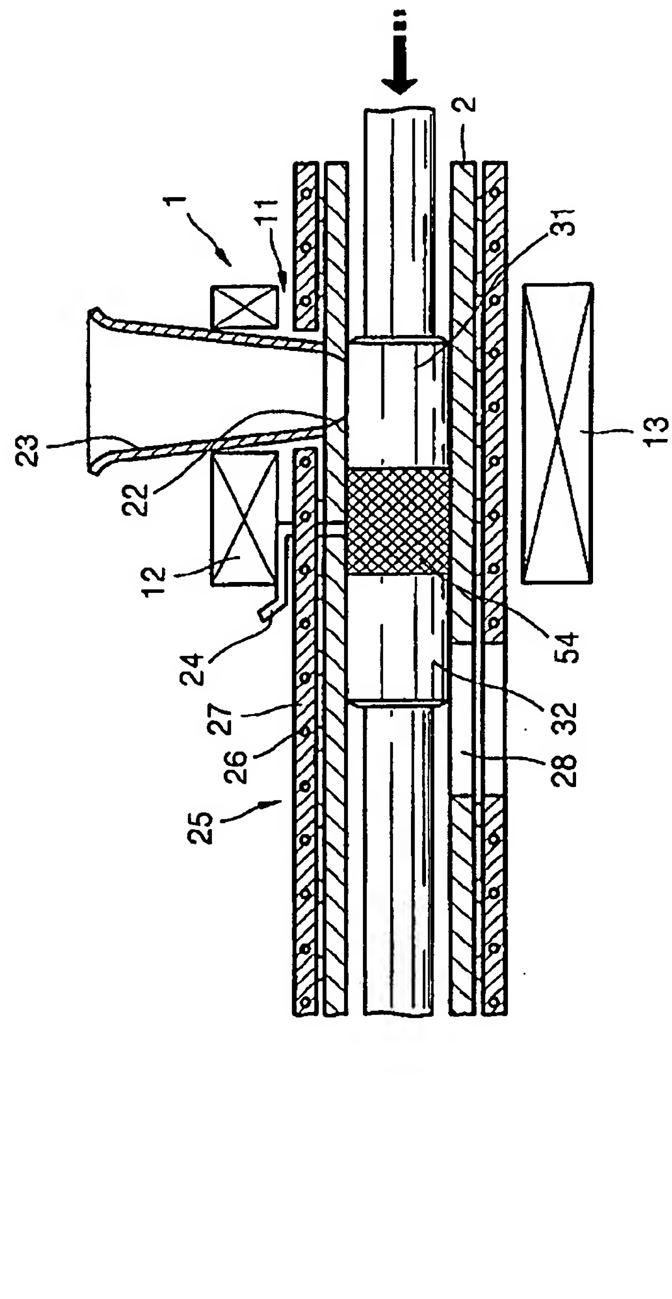


FIG. 10